The National Bioenergy Center and Biomass R&D Highlights

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National Renewable Energy Laboratory

NREL Technology Day
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Why Bioenergy?

- **Greenhouse warming**
  - Natural CO_2 cycle is 10X fossil fuels
- **National security**
  - 60% of our petroleum is imported
- **Sustainability**
  - Potential to replace petroleum-derived fuels and chemicals
- **Rural economic benefit**

National Bioenergy Center

Announced by Dept of Energy Secretary Bill Richardson at the Kansas City Board of Trade on October 31, 2000

NREL Role: *Coordinate research at DOE labs*

NETL

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

INEEL
Idaho National Engineering and Environmental Laboratory

Argonne National Laboratory
Operated by the University of Chicago

OAK RIDGE NATIONAL LABORATORY

NREL

Bioenergy Strategic Goals

U.S Dept of Energy

Protect national and economic security by promoting a diverse supply of reliable, affordable, and environmentally sound energy

- Reduce our dependence on foreign oil
- Create the new domestic bioindustry

National Bioenergy Center

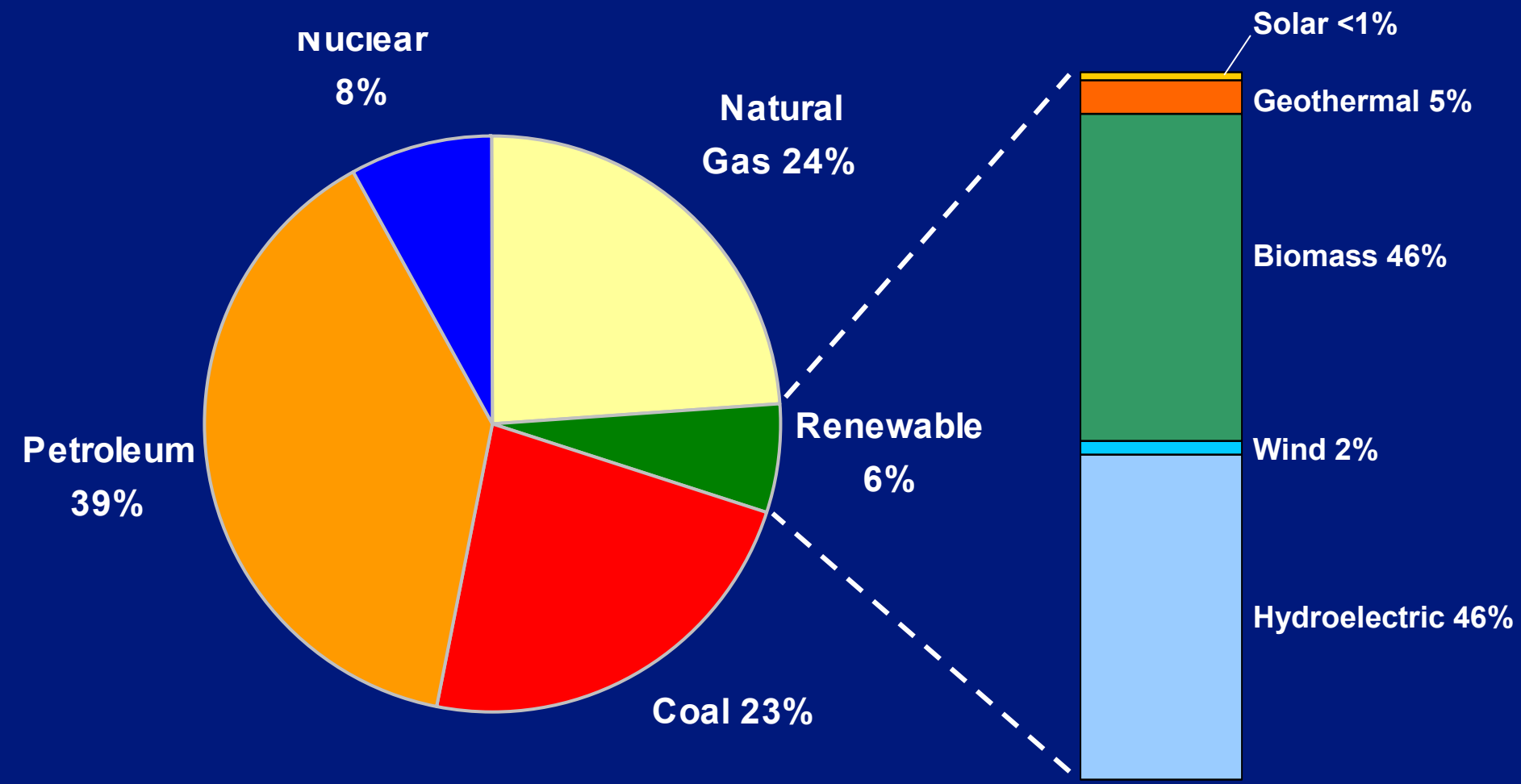
Develop biomass-based technologies that will be used by the U.S. transportation fuel, chemical and power industry

Specific Goal

Help establish technology for large-scale biorefineries based on agricultural residues by 2010

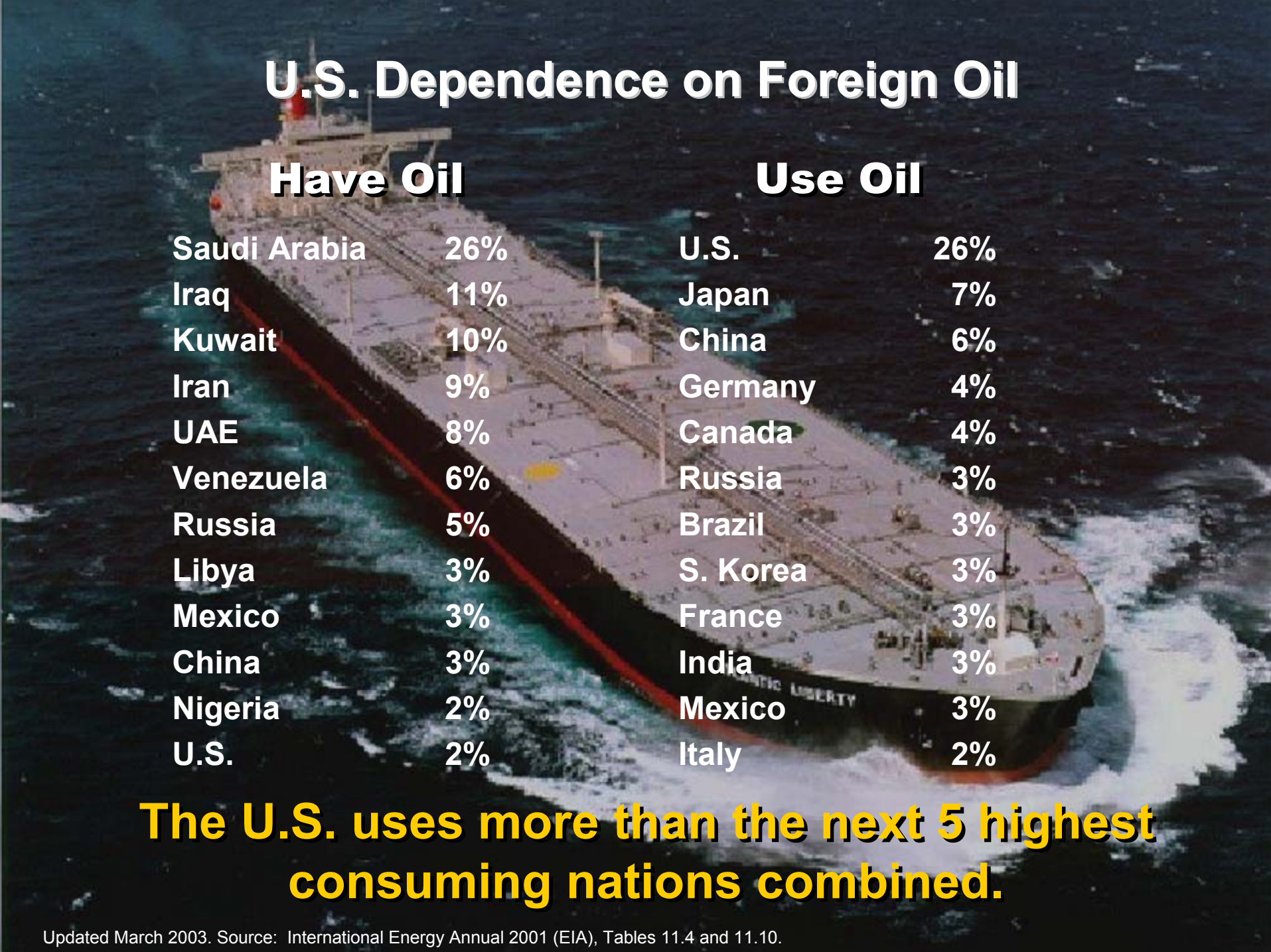
Share of U.S. Energy Supply

(data for 2002)



Source: AEO 2004 tables (released in December 2003) based on US energy consumption. Overall breakdown Table A1 (Total Energy Supply and Disposition), and Renewable breakdown Table A18 (Renewable Energy, Consumption by Section and Source).

U.S. Dependence on Foreign Oil



Have Oil		Use Oil	
Saudi Arabia	26%	U.S.	26%
Iraq	11%	Japan	7%
Kuwait	10%	China	6%
Iran	9%	Germany	4%
UAE	8%	Canada	4%
Venezuela	6%	Russia	3%
Russia	5%	Brazil	3%
Libya	3%	S. Korea	3%
Mexico	3%	France	3%
China	3%	India	3%
Nigeria	2%	Mexico	3%
U.S.	2%	Italy	2%

The U.S. uses more than the next 5 highest consuming nations combined.

Updated March 2003. Source: International Energy Annual 2001 (EIA), Tables 11.4 and 11.10.

The Unique Role of Biomass

While the growing need for sustainable electric power can be met by other renewables…



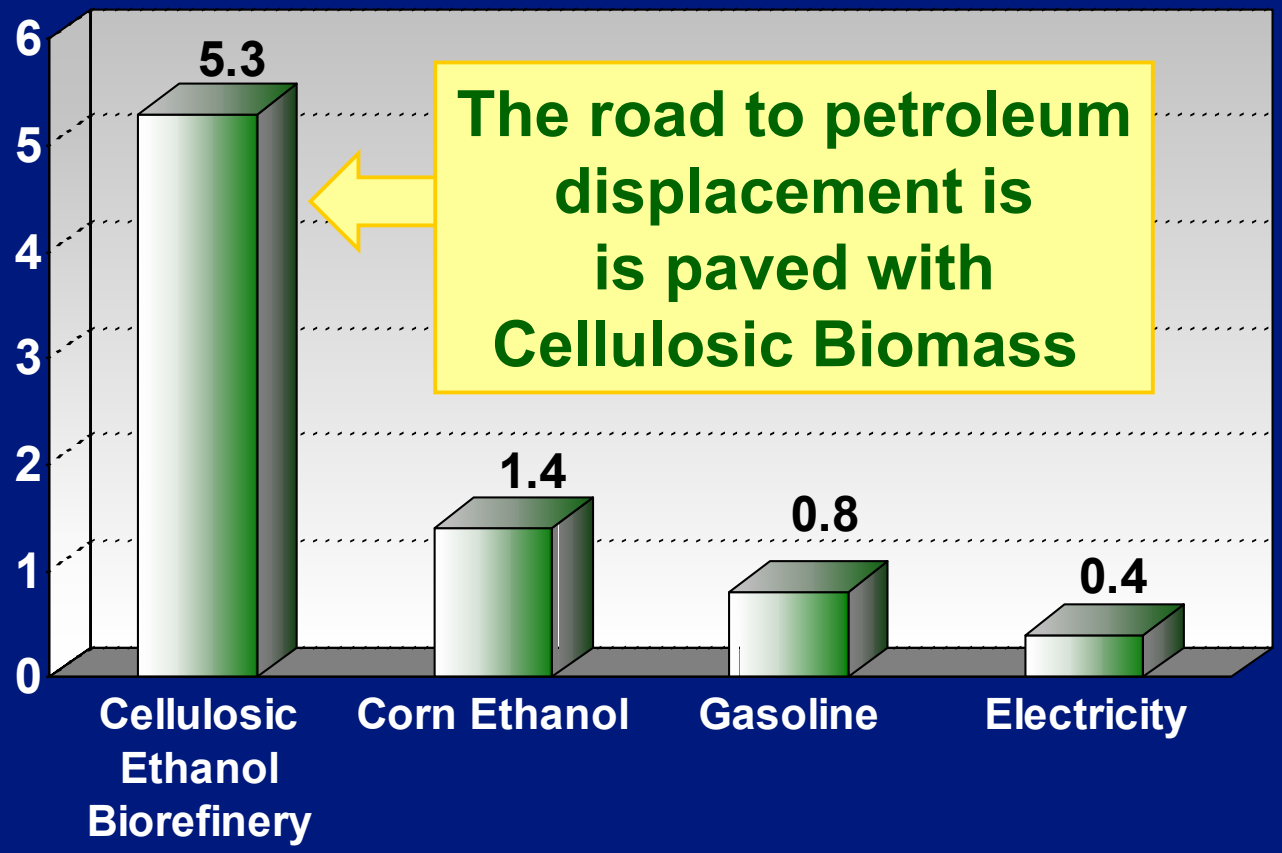





Biomass is our only renewable source of carbon-based fuels and chemicals

Fossil Energy Replacement Ratio

$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$



Source: J. Sheehan & M. Wang (2003)

Biomass Chemistry 101

Lignin: 15-25%

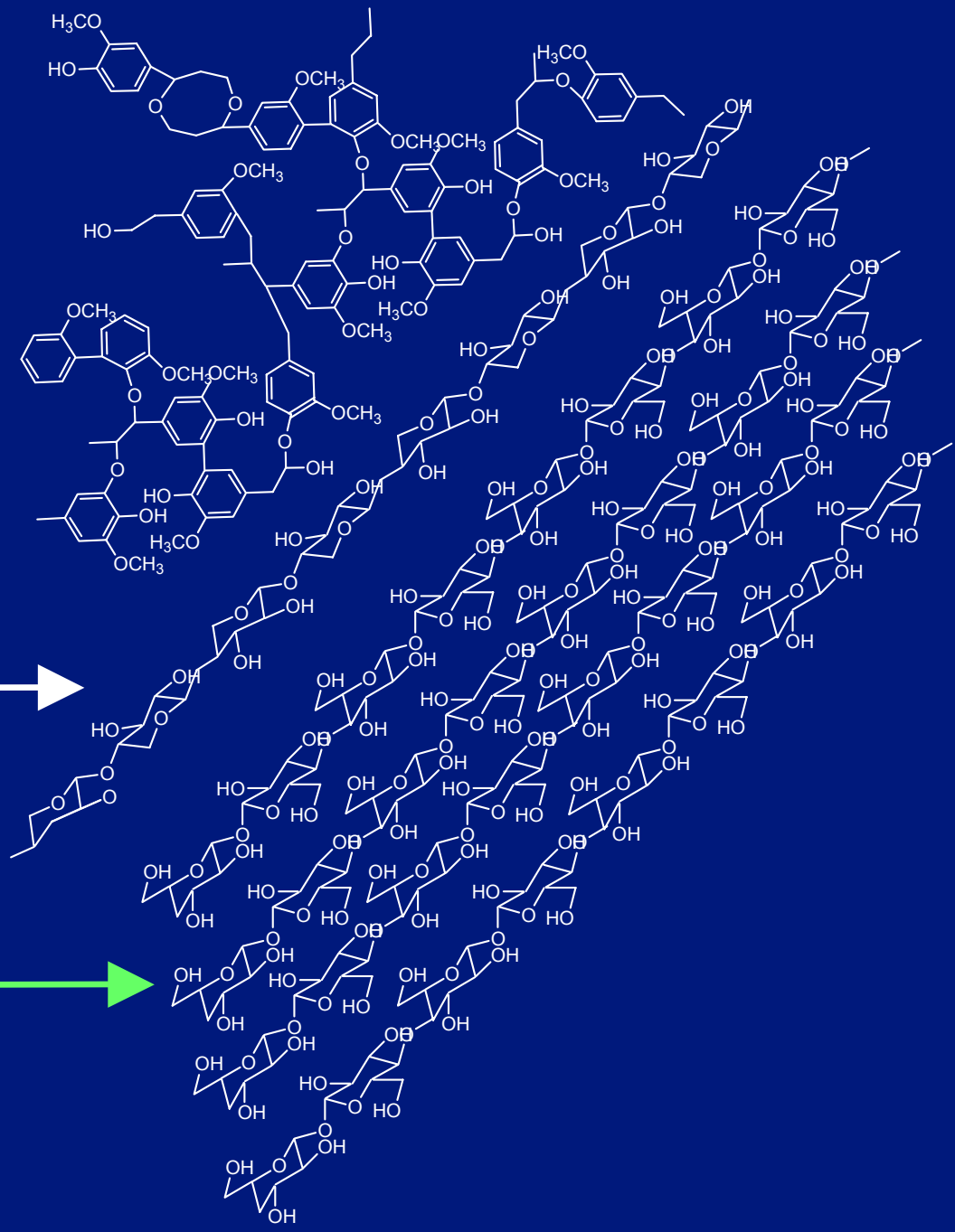
- Complex aromatic structure
- Resists biochemical conversion
- Requires high temperatures to convert

Hemicellulose: 23-32%

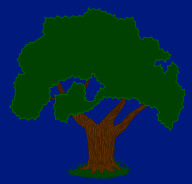
- Polymer of 5- and 6-carbon sugars
- Easily depolymerization
- 5-carbon sugars hard to metabolize

Cellulose: 38-50%

- Polymer of glucose
- Susceptible to enzymatic attack
- Glucose easy to metabolize

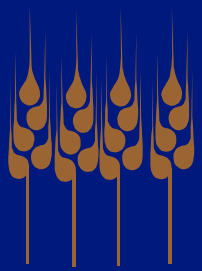


Cellulosic Biomass Composition



Hardwoods

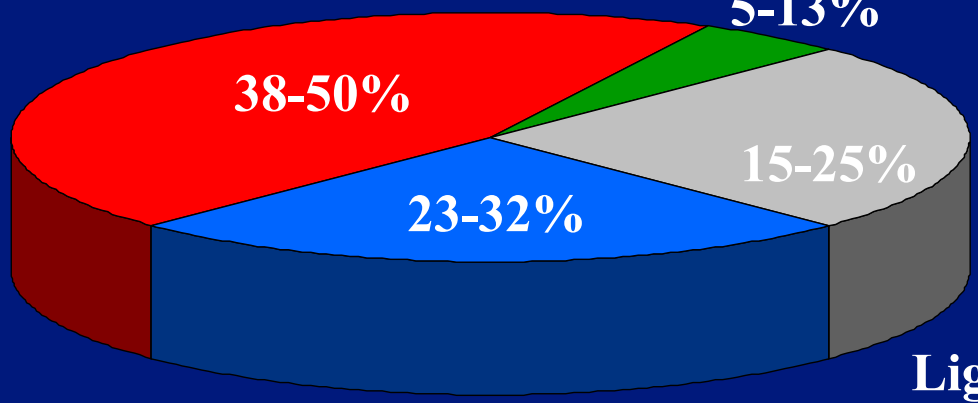
Grasses



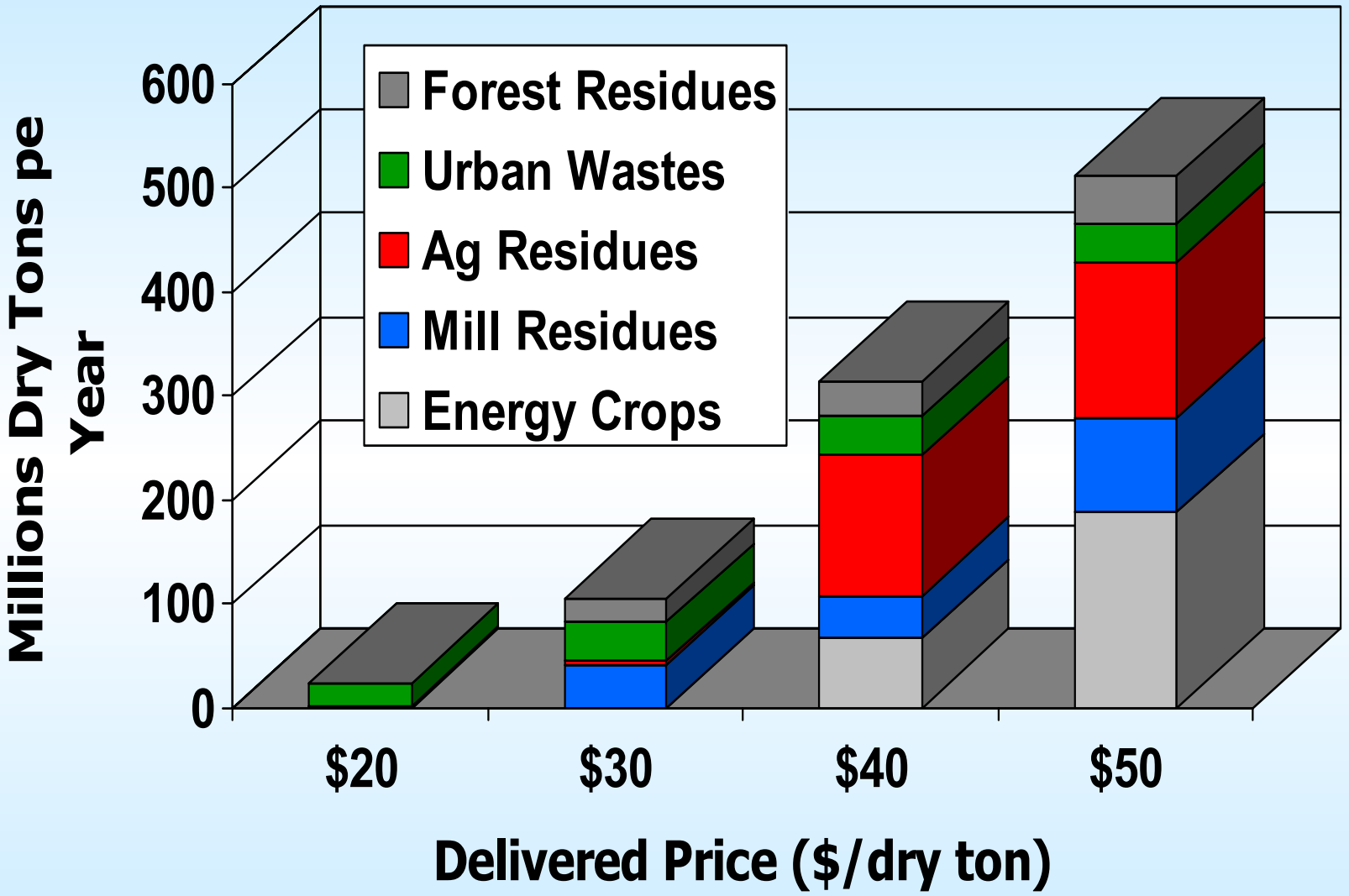
Crop residues

MSW

Softwoods

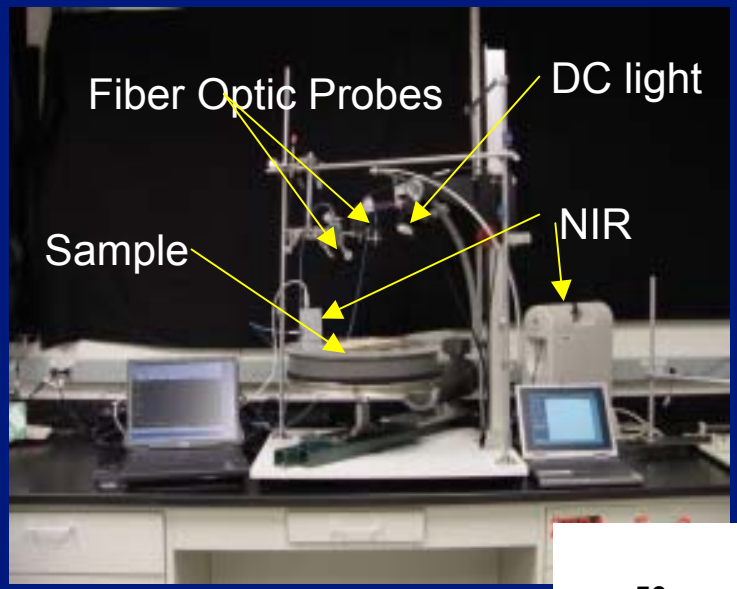


2020 U.S. Biomass Supply Potential



Developing 1 billion ton case for 2050

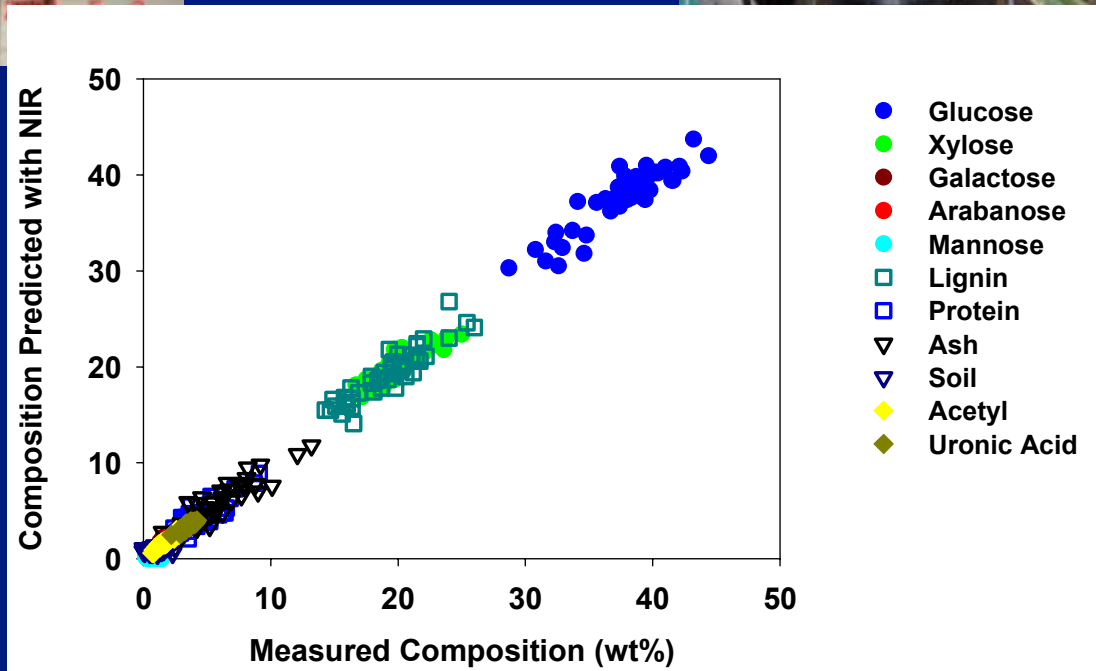
NREL's Rapid Analysis Technology



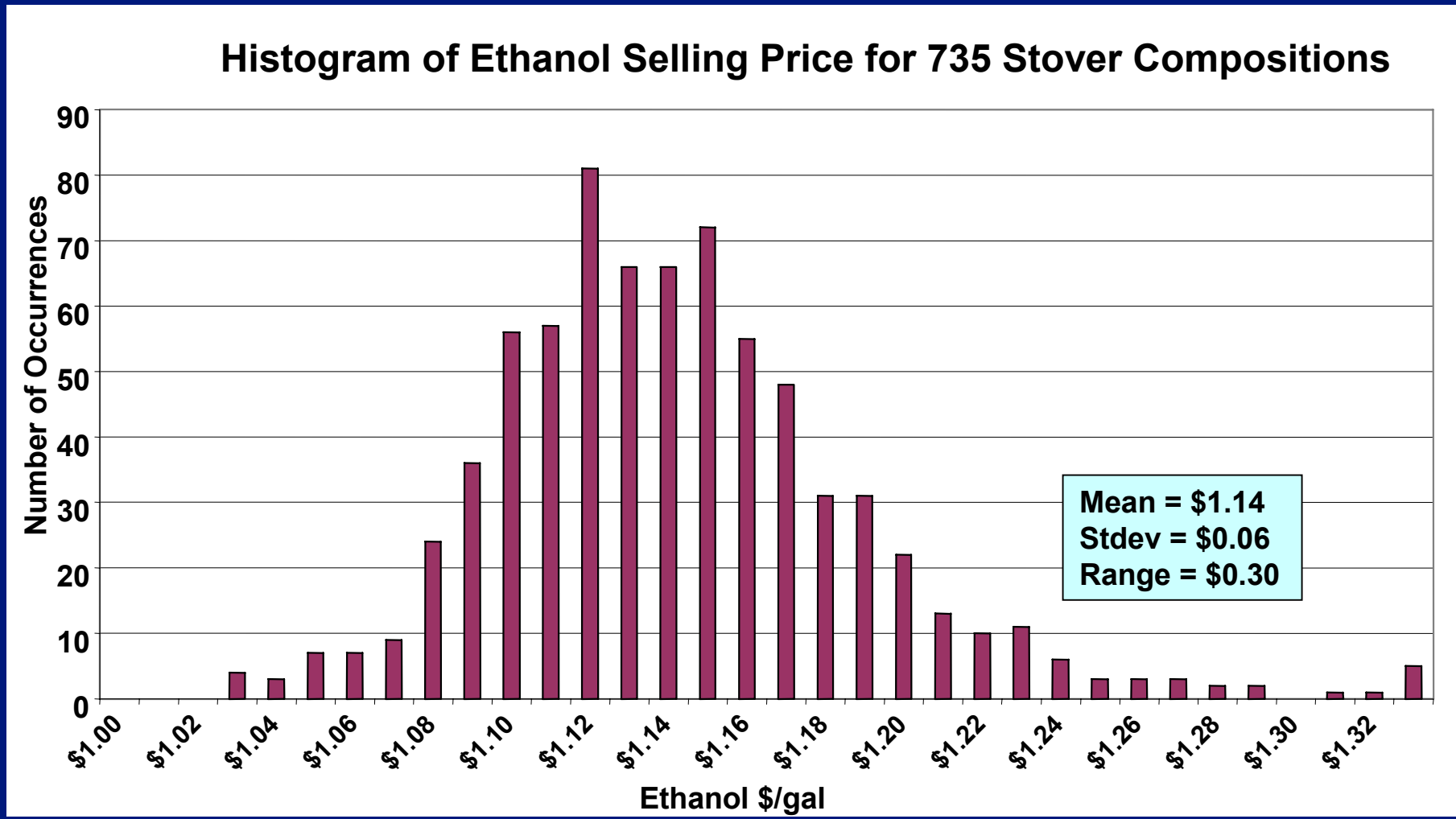
Predicts biomass feed performance in biorefinery

Feed quality measurement in the field

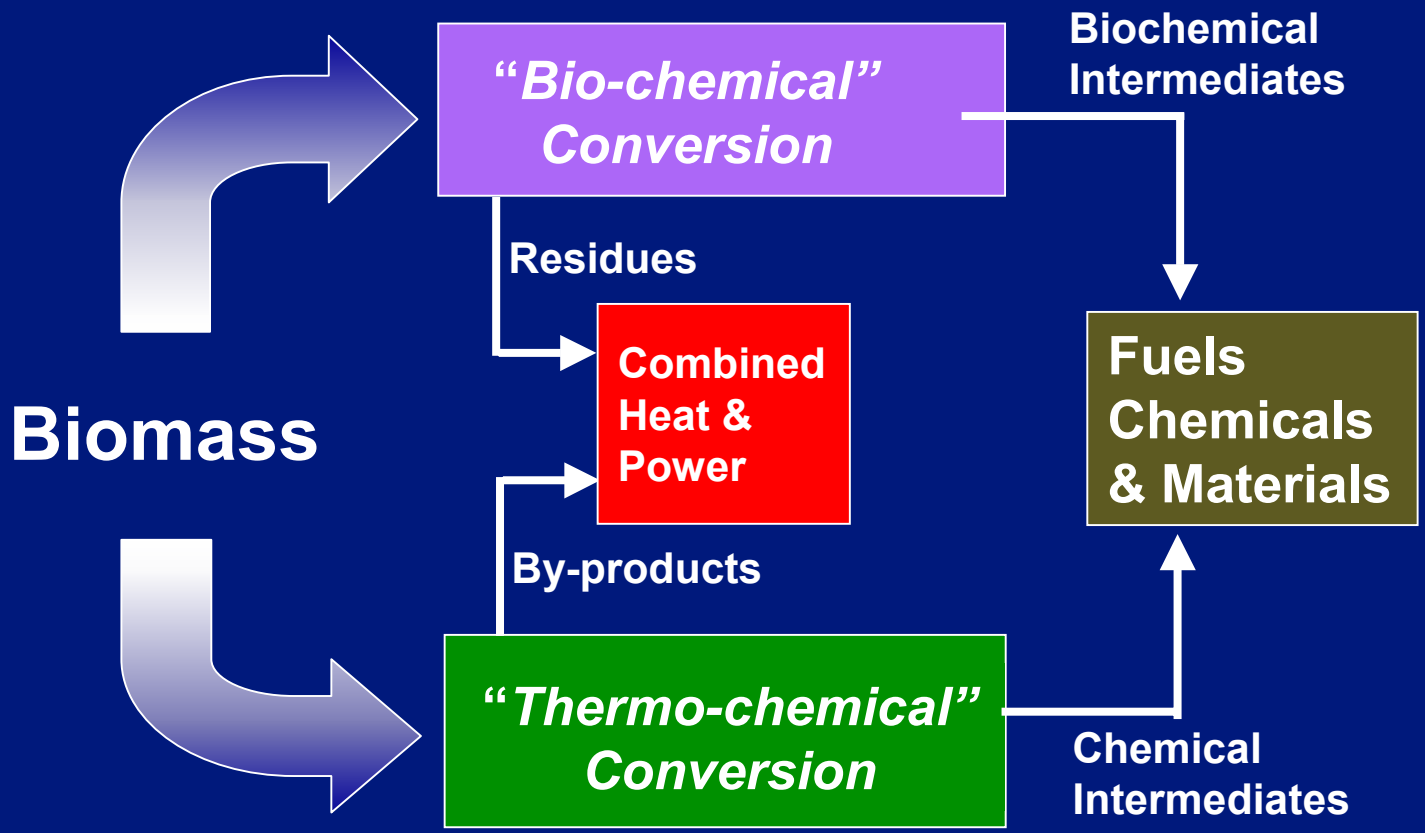
Near Infrared combined with multivariate methods



Rapid Analysis Methods are Critical to Quantify the Impact of Feed Variability



Cost of "*Conversion Platforms*" Drives Biomass R&D at NREL



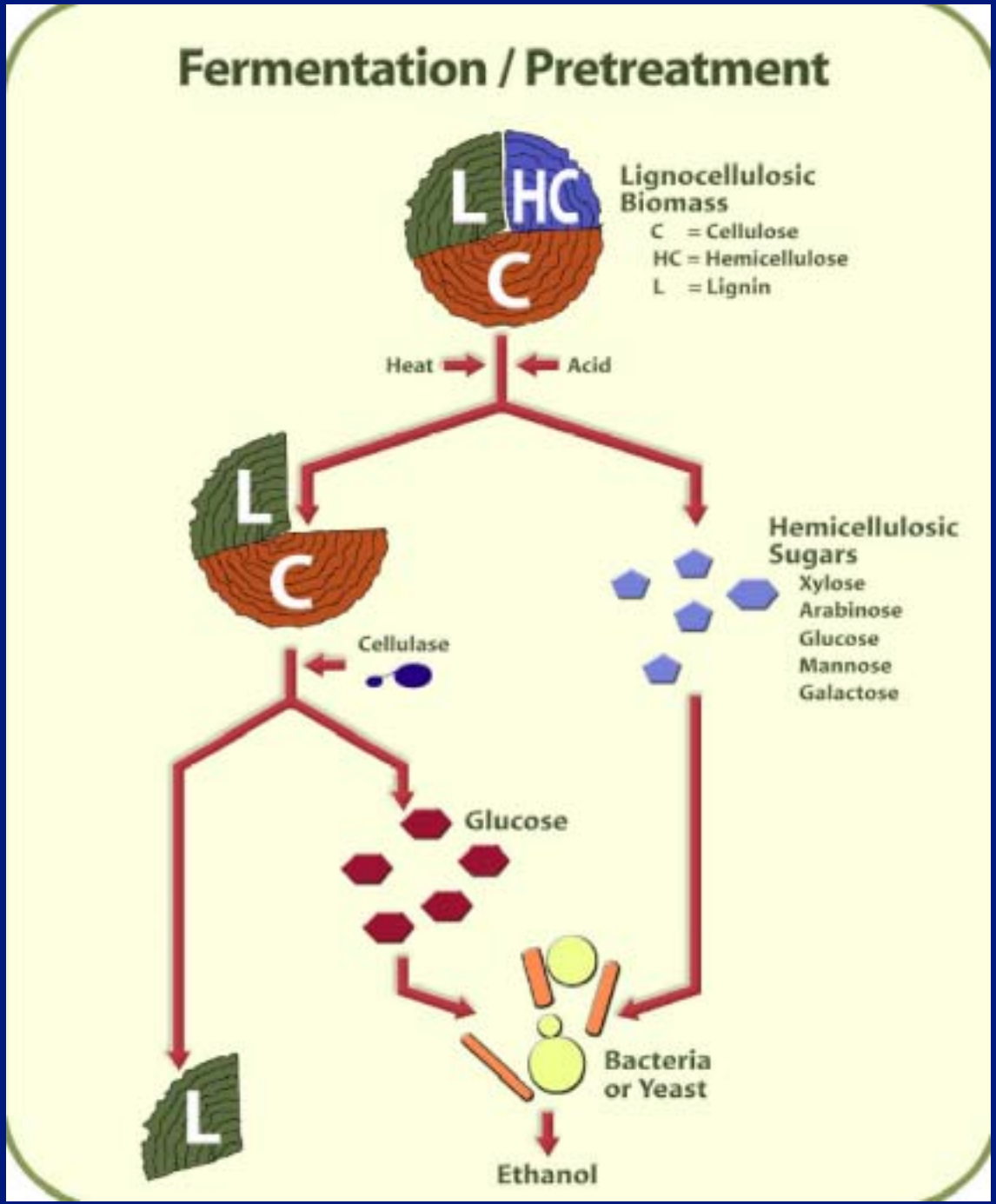
Why 2 Platforms?

Bio-Chemical ~~Technology~~

effective for cellulose and hemicellulose

Thermochemical ~~Technology~~

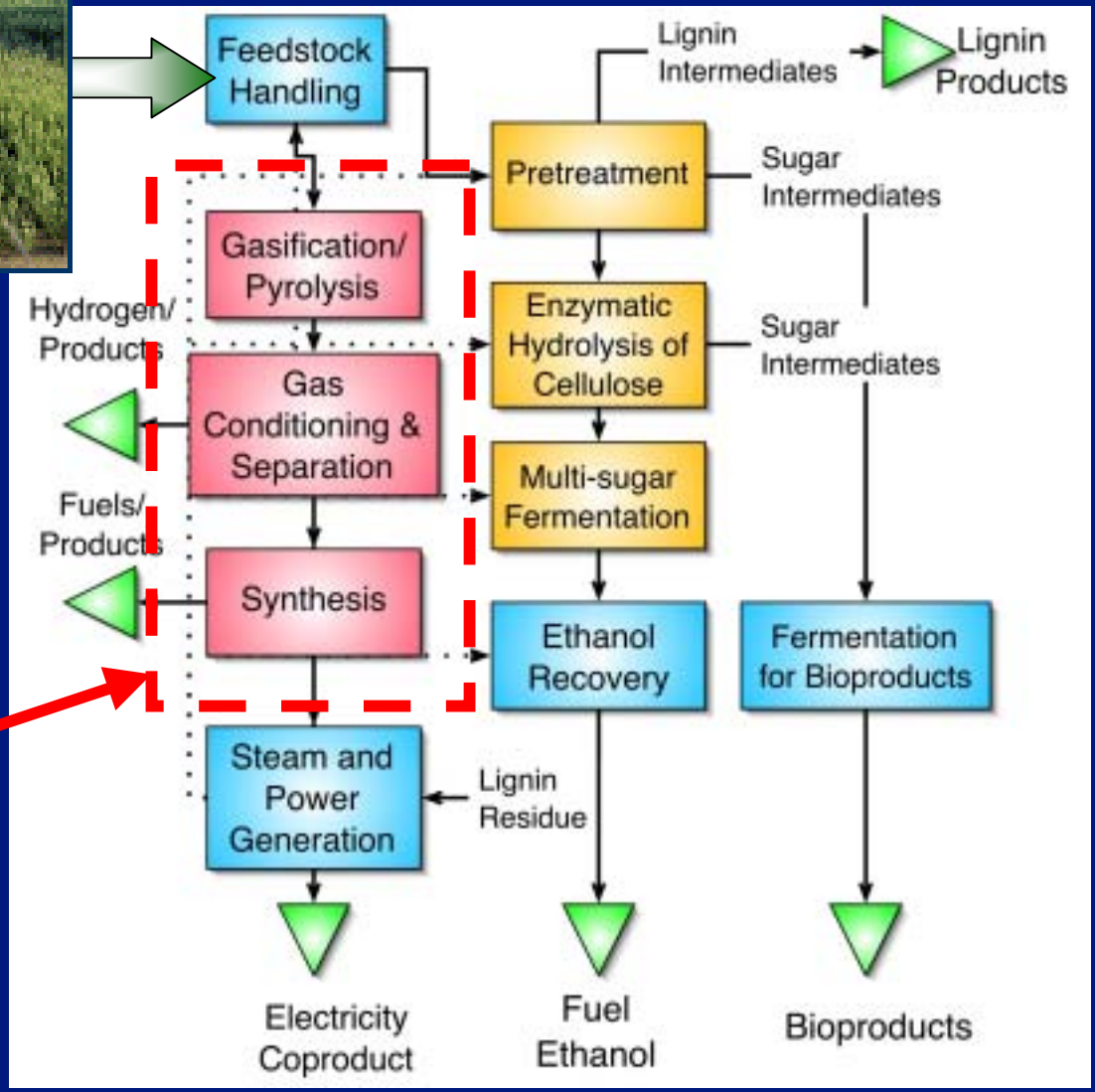
needed to convert the lignin fraction, or the whole biomass



Essential Technology for Biorefineries

An integrated biorefinery will make use of:

- Thermochemical conversion technology
- Biochemical conversion technology
- Existing technology



NREL's Thermochemical User Facility

- Simulates thermochemical conversion processes
  - Pyrolysis
  - Combustion
  - Gasification
- Fully integrated
- Accommodates testing of close-coupled biomass conversion with upgrading
- Various size scales
  - 0.1 kg/h bench-scale reactors to 20 kg/h

Available for Contract R&D

NREL Capabilities in Gasification

Biomass Feeder

SynGas Production, Cleaning and Conditioning

Fluidized Bed

Gas Cleanup

Gas Conditioning

Hydrogen Production

Biological Reactor

Steam Reforming

Liquid Fuels

Fischer-Tropsch

Chemicals

Power

Engine, Fuel Cell, Or Turbine

Electricity

Heat

Combustion

Electricity

Thermochemical Conversion Projects

Example: *Gasification to Power*

3 Small Modular Power Systems installed in 2003

Example: North Park High School Walden Colorado

Strong Community Support

Power & Heat for Greenhouse

Fuel: forest thinning residues

Load: 8 kW

Maintenance: 30 minutes per week

Operated by Students

Thermochemical Conversion Projects

Example: *Pyrolysis to Phenolic Resins*

- Multi-year $2.4 million DOE project
- Builds on 15+ years of R&D at NREL
- Commercial pyrolysis partner - Ensyn
- Cost share by resin manufacturers
- CRADA with Wood Product companies
  LP, Weyerhaeuser, Tembec

-Successful "mill trial" at OSB mill

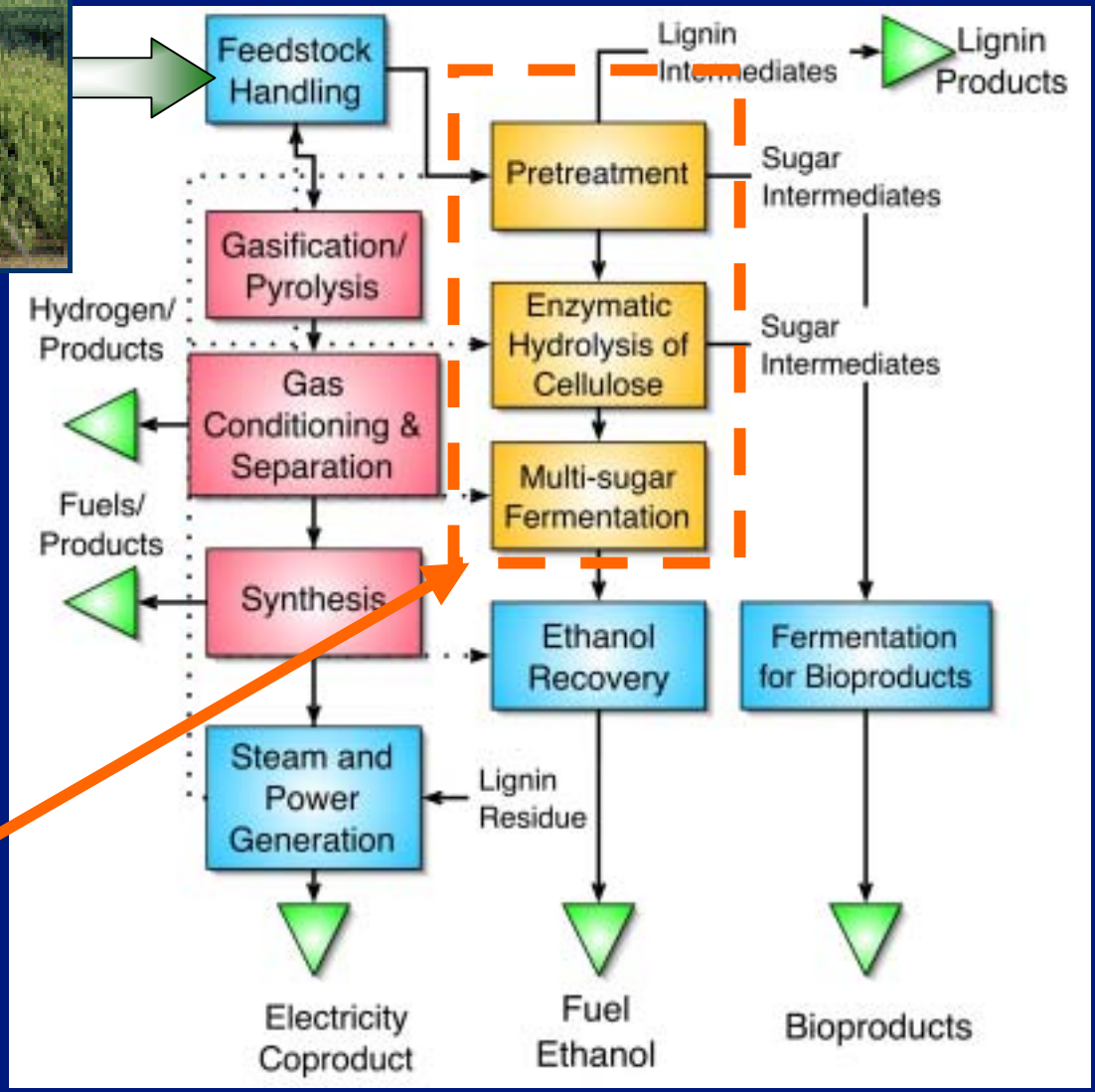
- Product certification complete

NREL Technology for Future Biorefineries

An integrated biorefinery will make use of:

- Thermochemical conversion technology
- Biochemical conversion technology
- Existing technology

Available today



Dilute Acid Pretreatment Of Lignocellulosic Biomass

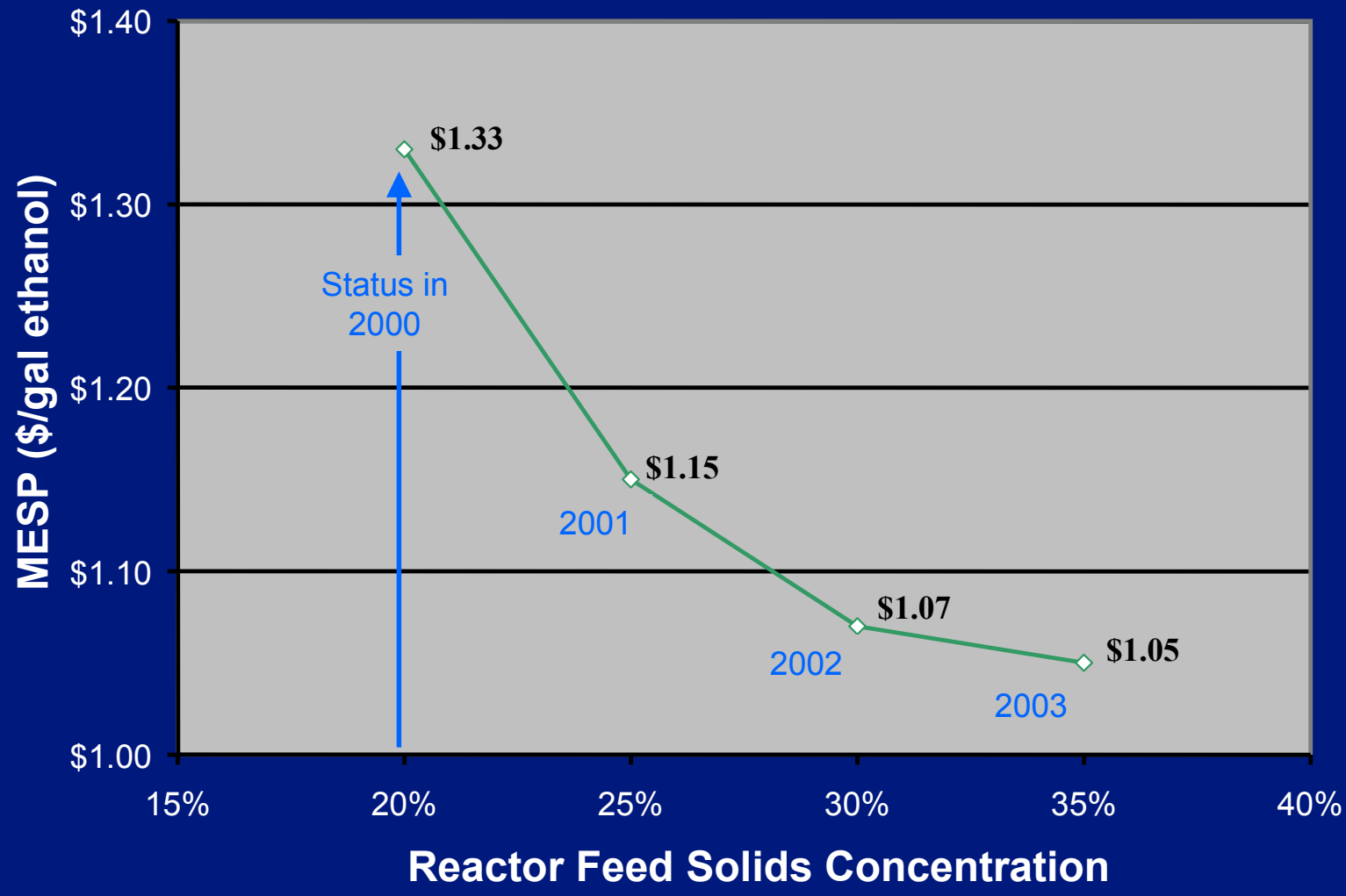
1 ton/day Sunds Continuous Pretreatment Reactor

- Patented technology available for licensing
- User Facility for contract R&D

Untreated Corn Stover

Pretreated Corn Stover at 35% solids loading

ASPEN Modeling Capability to Quantify Economic Impact of Process Advances

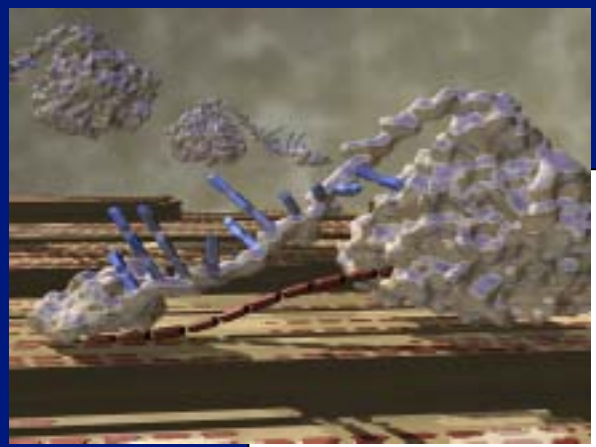


Process Design described in a design report available at http://www.nrel.gov/docs/fy02osti/32438.pdf

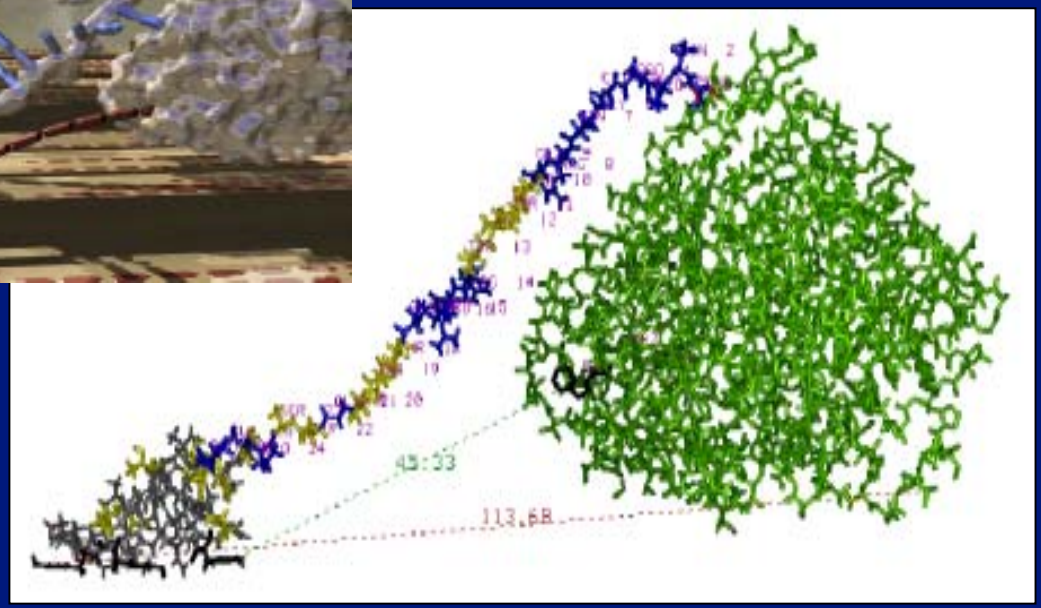
NREL's Enzymatic Hydrolysis Research

3-year Partnerships with Genencor & Novozymes

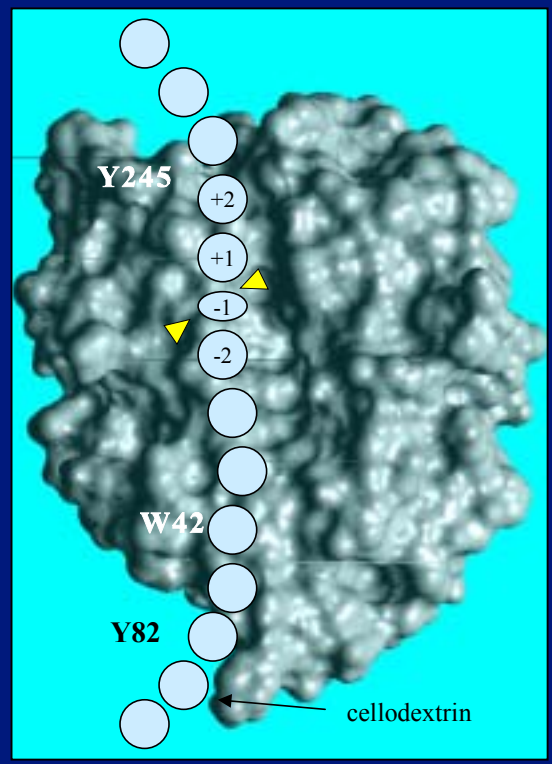
- Focus on enzyme biochemistry, cost, and specific activity
- Investigate enzyme - substrate surface interaction
- 10-fold reduction in cost of enzyme production



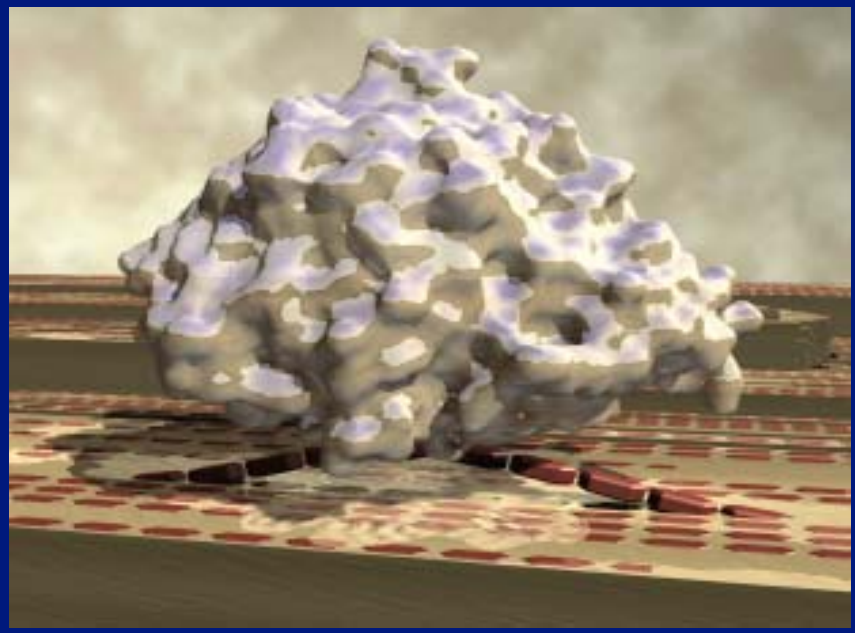
CBH1 from T. reesei



E1 from *A. cellulotiticus*



Acidothermus cellulolyticus E1 Enzyme

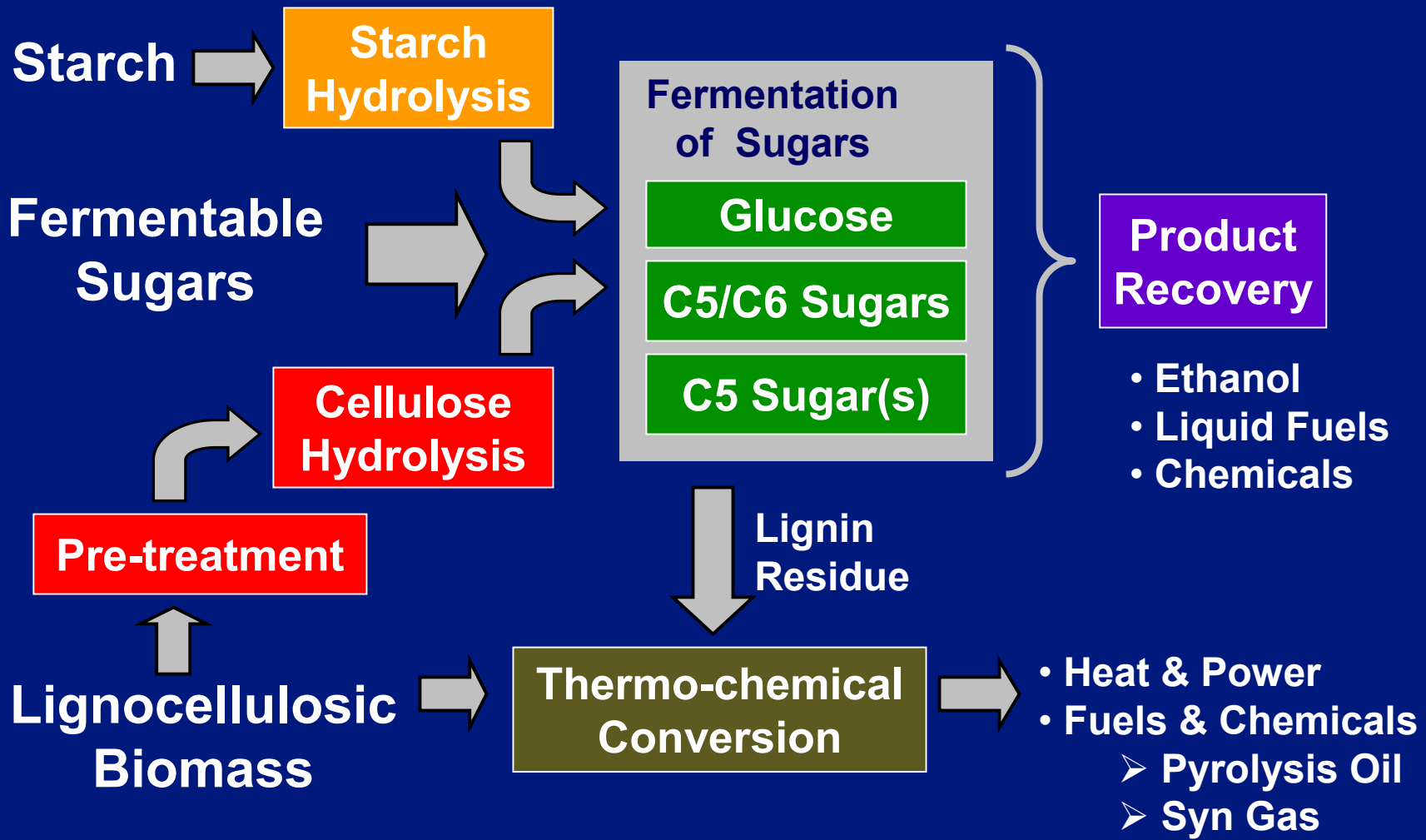


- A themotolerant cellulase with applications in the paper, detergent, textile, animal feed, food, waste treatment, and agricultural industries

- Patent numbers: 5,110,735; 5,275,944 ; 5,366,884; 5,514, 584; 5,536,655 and patents pending.

- Example of patented technology available for licensing

Integrated Biorefinery Elements



Partnership Example

Dupont-NREL: *Integrated Corn Biorefinery*

- $38 million (50% from DOE)
- $8 million to NREL
- Goal:

  develop a Process Design Package for farmers to produce fuels, chemicals and power from entire corn plant

- License to use NREL organism
- 4-yr timeline

building block for Sorona™ polyester

corn →
corn stover →

→ chemicals
→ bioethanol
→ power

Sorona™

400% AAGR

NREL's Role: *Support the Development of New Industrial Biorefinery Concepts*

Biomass Feedstock

– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

Conversion Processes

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Combustion
- Co-firing

USES

Fuels:
– Ethanol
– Renewable Diesel

Power:
– Electricity
– Heat

Chemicals
– Plastics
– Solvents
– Chemical Intermediates
– Phenolics
– Adhesives
– Furfural
– Fatty acids
– Acetic Acid
– Carbon black
– Paints
– Dyes, Pigments, and Ink
– Detergents
– Etc.

Food and Feed

Life Cycle Assessment

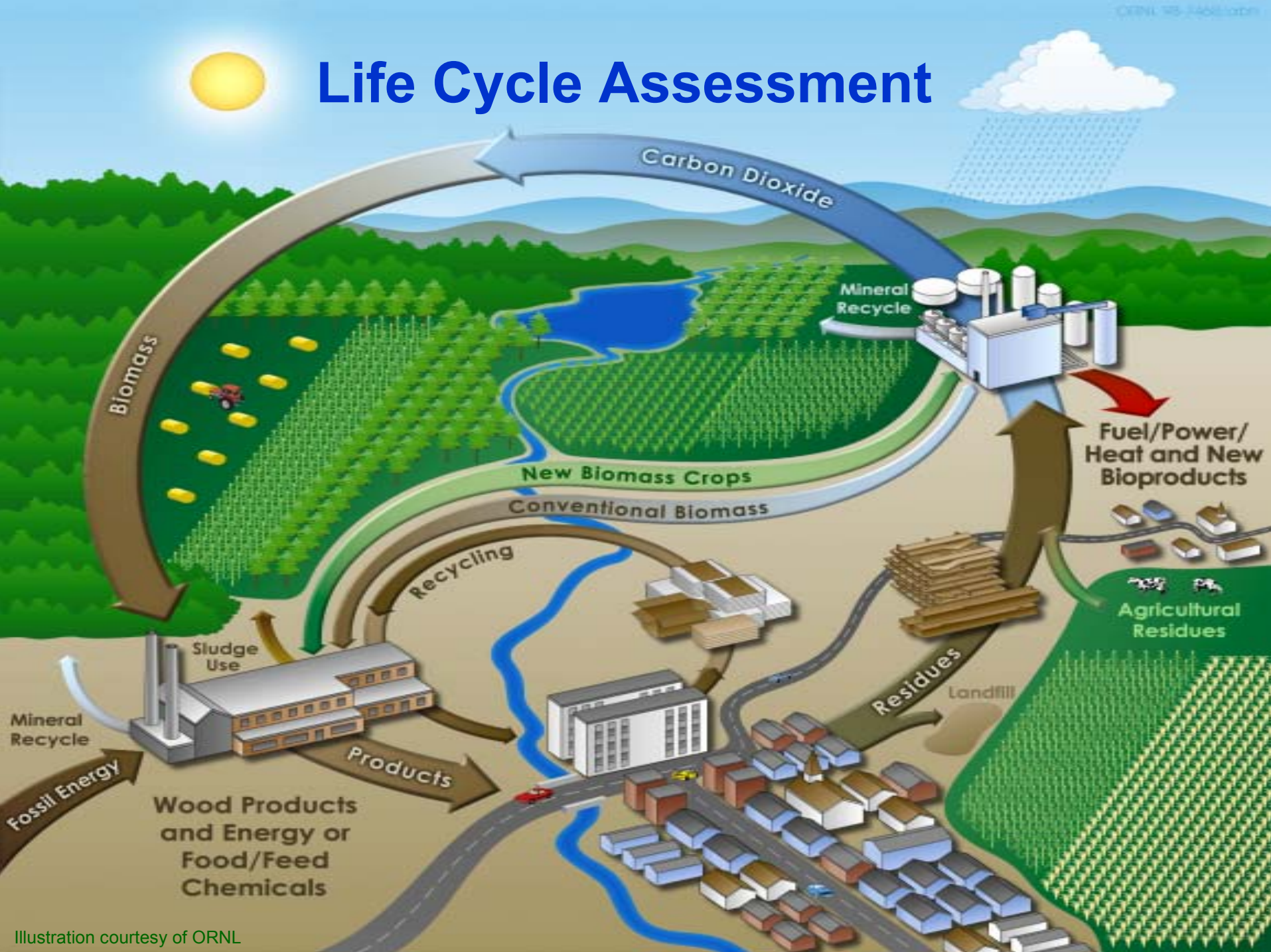


Illustration courtesy of ORNL

Opportunities other than Ethanol

- Sugar-derived chemicals
- Lignin derivatives (BTX, phenols, etc.)
- Biodiesel & chemicals from vegetable oils
- Pyrolysis oils from biomass
  - Oxygen rich *"cracked stocks"*
  - Exploring options for refining/upgrading
- Gasification of biomass
  - Fischer-Tropsch liquids
  - Hydrogen
  - Chemicals

Corn Stover Opportunity

- **Candidate for commercialization of biorefinery in 5-10 year horizon**
  - 100 million tons per year of available feedstock
  - Suitable for lignocellulosic biorefinery demonstration
  - Large impact on displacing petroleum
- **Synergy with fuel industry issues**
  - MTBE phase-out (Clean Air Act Amendments)
  - Impending Renewable Fuel Standard

Hydrogen from Biomass Opportunity

- Continuously supply
  - Intermittent renewables suffer from time-mismatch between resource availability and hydrogen demand
- Combined heat / power / fuels / chemical opportunities
- Chemical co-product opportunities (biorefinery concept)
  - PF resin, carbon black, activated carbon, carbohydrate derivatives (levulinic acid, ethanol, furfural, formic acid, succinic acid), polymers (PLA, 3GT polyester), FT synthesis (diesels, waxes, methanol, etc.)

Forest Thinning Opportunity

- Western states faced with critical forest management issues and risk of forest fires
  - Severe fuel loading problem
  - 600,000 tons of air pollutants emitted from 2002 CA wildfires
  - Billions of dollars spent on fighting fires and property damage
  - NREL platform technologies offer a means to convert forest thinning materials into fuels, energy, and/or chemicals
- Synergy with fuel industry issues:
  - MTBE phase-out
  - Renewable Portfolio Standard
- Feasibility studies in-progress

Pulp & Paper Mill Diversification Opportunity

- Source of dilute xylose upstream of pulping
  - Simplify pulping step
  - Reduce use of pulping chemicals
  - Large year-round source of fuels and/or chemicals
- Black liquor gasification
  - More efficient use of forestry resources
  - Low cost source of Syn Gas from biomass
  - Options for MeOH, DME, FTL, and chemicals
- Diversification of revenue to pulp mill
  - Provides U.S. mills with competitive advantage in international markets

Summarizing The Biomass Value Proposition

- Only sustainable source of hydrocarbon-based fuels, petrochemicals, and plastics
- Huge U.S. and worldwide potential biomass resource base
  - potential to displace over 50% of U.S. gasoline and diesel consumption with domestic resources
- Reduction of greenhouse gas emissions
- Reinvigorate and diversify rural economy
- Targeted technology advances can create new business opportunities

The National Bioenergy Center is led by NREL and funded by the Office of Biomass Program within the U.S. Department of Energy